AL-TR-1991-0068

AD-A238 808

ARMSTRONG LABORATORY

WOMEN IN THE MILITARY COCKPIT

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June 1991

Final Technical Report for Period 1 January - 30 January 1991

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AIR FORCE SYSTEMS COMMAND
BROOKS AIR FORCE BASE, TEXAS 78235-5000

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Environmental Health Directorate

REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
June 1991

3. REPORT TYPE AND DATES COVERED
Final 1 Jan - 30 Jan 91

4. TITLE AND SUBTITLE
Women in the Military Cockpit

5. FUNDING NUMBERS

6. AUTHOR(S)
Terence J. Lyons

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Armstrong Laboratory/OE
Occupational and Environmental Health Directorate
Brooks AFB TX 78235-5000
(Formerly: AF Occupational and Environmental Health Laboratory (AFOEHL))

8. PERFORMING ORGANIZATION REPORT NUMBER
AL-TR-1991-0068

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)* Historically women have demonstrated the capacity to be successful aviators. Recent participation of women in combat roles and in military aviation has, however, aroused controversy. The scientific literature pertinent to the role of women in military aviation was reviewed. Cognitive differences between men and women account for less than 5% of the population variance and their implication for aviation is unknown. The effect of cyclic hormone fluctuations on performance is poorly understood. Men are, on the average, larger, stronger, and more fit than women, although there are large variations within each sex and a large overlap between the sexes. Difference in work performance, injury rate, etc., disappear when size, strength, and fitness are controlled for. Selection criteria can thus address size, strength, and fitness requirements without reference to sex. Several minor differences of questionable operational significance may exist. Women may be more susceptible to motion sickness, heat stress, radiation (cancer and endometriosis), and decompression sickness than men, but may be more resistant to cold stress and altitude sickness. The possibility of fetal damage in the early stages of pregnancy (before diagnosis of pregnancy) appears to be perhaps the biggest single medical concern in allowing women access to all aviation/space careers.

14. SUBJECT TERMS
Female, Pilot, Anthropometry, Pregnancy, Altitude Acceleration

15. NUMBER OF PAGES
52

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18

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I. INTRODUCTION

Aviation history is full of women who have made notable contributions. The role of women in the military, however, is controversial and political. The issue is often discussed in the popular press. During World War I and World War II women served in the military primarily as nurses. Women were integrated into the military services in 1948 by the Women's Armed Services Act, but were still excluded from combat duties (Holm:113). This combat exclusion was the basis of excluding women from pilot training (Holm:126). The role of women in the military has increased markedly in recent years. Women are also playing an increasing role in combat operations. Women in the recent 1990 Panama campaign, however, participated in combat roles, and this sparked controversy.

The role of women in military aviation remains an area of current controversy. Women in the U.S.S.R. began to play prominent roles in military aviation during World War II; because of severe personnel shortages, women were used as combat pilots with notable success (Holm:315). Women served during World War II in the Women's Air Ferrying Squadron (WAFS) starting in 1942 in the non-combat roles of ferrying aircraft and acting as flight instructors (May:148) (Rock:113/see Anthropometry references) (Holm:315). The elimination rate during pilot training was lower for women (Rock:105/see Anthropometry references), and the accident rate was comparable to that for men (Rock:106) (Holm:315). The training of female pilots, ended in the U.S. in 1944, was resumed again in the 1970's. The Navy graduated its first female pilots in 1973 (Blower:2/see Cognitive and Psychological Factors references), the Army in 1974, and the Air Force in 1977 (Holm:317-319). Other Western nations made similar decisions: Canada beginning to train female pilots in 1979 (Hicks/see Cognitive and Psychological Factors references), Norway in 1982 (Myhre/see Cognitive and Psychological Factors references), and the

United Kingdom in 1989 (Turner/see Anthropometry references). The numbers of female pilots in U.S. military aviation remains small. By 1989 there were only 225 female pilots in the Navy (1.8% of a total of 12,477) (Blower:1), and 314 in the USAF (just over 1% of a total of 25,000) (personal communication, HQ USAF). In the Army, females make up 1.2% of the aviator population (Edwards:3/see Illness and Injury references).

The combat restriction remains a controversial part of U.S. policy. In 1989 the USAF selected its first female test pilot. Recently the USAF has decided to train women into high altitude U-2/TR-1 aircraft (Strategic Air Command Scientific Advisory Board/see Pregnancy references). Women in the U.S. and the United Kingdom (Turner/see Anthropometry references) are not currently assigned to combat aircraft. Women in Norway (Myhre/see Cognitive and Psychological Factors references) and Canada (Hicks/see Cognitive and Psychological Factors references) are assigned to all types of military aircraft.

This paper will address primarily the physical, physiologic, and medical difference between men and women. However, because the cognitive and psychological aspects of performance are perhaps even more important to safe flight than the physical aspects, these will be briefly reviewed. Anatomic, physiologic, fitness, anthropometric, and strength differences are all relevant to the aerospace environment. As the scientific literature on these areas is voluminous, they will be briefly reviewed and the relevance to the aerospace environment highlighted. A more thorough review will be done on the scientific literature addressing the differences between males and females in their responses to aeromedical stresses of acceleration, hypoxia, changes in barometric pressure, temperature extremes, and radiation. The likelihood of inflight medical incapacitation and adverse effects on pregnancy will also be discussed.

There are many other issues related to the issue of women in the cockpit, such as public opinion, effects of women on unit esprit de corps, the psychological fitness of women for combat, fairness to women in career

advancement, etc. In the interest of brevity, none of these issues will be addressed in this paper.

II. GENERAL ASPECTS OF FEMALE PERFORMANCE

COGNITIVE AND PSYCHOLOGICAL FACTORS

The literature on cognitive differences between the sexes is voluminous, complex, and controversial. Some differences have been found between men and women. For example, it has been stated that there are some basic male/female differences in brain lateralization. Of specific interest to aviation are the areas of spatial abilities and vigilance. Males have been demonstrated to be quicker than females in forming a mental "picture" and in distinguishing left and right (Crowley:37). Men performed better in spatial tasks (Galluscio:7). Females, on the other hand, were faster when a verbal strategy is appropriate (Crowley:37), and performed better in verbal tasks (Galluscio:7). The alleged male superiority in spatial ability, however, has been challenged in that gender-related differences were very small and inconsistent from study to study (Caplan:786). The literature addressing the effect of menstruation on cognitive performance is controversial. One review article concludes that the "weight of the evidence argues against a menstrual cycle effect on behavior" (Sommer:53/see Anatomy and Physiology references).

Studies of monitoring and vigilance have been apparently contradictory. One study demonstrated a 10% poorer average performance by females in a simple monitoring task (Waag:272). Inter-subject variability was great, however, and sex accounted for only between 1 and 4% of the variation in this study. A recent Federal Aviation Administration (FAA) study of vigilance during a more complex monitoring task, however, found no sex-related differences

(Thackray:1215). Another study demonstrated no sex differences in a study of the effects of noise on both performance and subjective annoyance (Key).

Potential psychological differences between men and women are likewise controversial. Studies demonstrate that females exhibit less risk-taking behavior than males (Hudgens). Male-female social interaction is another area of concern. The tendency for male pilots to "role-cast" female pilots, has implications for flying safety (Jones DR/see Illness and Injury references). Over 80 studies have addressed female leadership abilities; however, only 7 of these studies included statistical analysis of a quantitative measure of performance. A review and meta-analysis of these 7 studies indicates no consistent and significant male/female differences (Farrell:34).

Determination of female psychological fitness for flying duty is complicated because aviators have a unique psychological profile. Female pilot candidates are not a representative sample of the U.S. female population. FAA studies of female Air Traffic Controllers (ATCs) have demonstrated them to be more like male ATCs than the population as a whole in their psychological profile (Karson). This is confirmed in studies of female divers (Morgan).

Some of the above suggested differences in cognitive performance and psychology have been confirmed in studies of pilot candidates. Among USAF pilot candidates, females performed better on verbal and fine dexterity tests, whereas males performed better on mechanical tests (Kantor:7). A Canadian study reported superior female ability in verbal ability and clerical speed/accuracy, but better male ability in tests of mechanical reasoning, visual spatial ability, and quantitative ability (Hicks). A Norwegian study demonstrated better female scores on tests of simultaneous capacity, but better male performance on tests of instrument comprehension, spatial orientation, and mechanical comprehension (Myhre). Overall female pilot candidates tend to be slightly lower than males on existing tests. The U.S. Navy, for example, reports significantly higher composite scores among male pilot candidates (Blower).

The operational significance of these findings, however, remains controversial. Studies of this area are confounded due to variation between individuals even of the same sex that is probably greater than gender-related differences- - gender differences accounting for no more than 1% to 5% of the population variance (Bleier:391) (Hyde:894). Recently female trainees in U.S. Air Force were noted to have had a higher attrition rate (34%) than male pilots (26%) (Ginovsky:8), but estimates of pilot attrition also vary widely for reasons other than the sex of the candidate. Women in U.S. Navy pilot training were reported to have lower training attrition and better retention than their male counterparts (Hutton). Attrition rates also vary from country-to-country (lower in many other NATO countries than in the U.S.), from year-to-year (overall student pilot attrition in the USAF was 37% in 1987, 27% in 1988, and 25% in 1989) (personal communication HQ TAC/SGPA), and from service to service (U.S. Navy attrition in pilot training averages only about 10% (Blower:6)). U.S. Air Force flight instructors in one study rated males higher for strength, endurance, ability to manage stress, and overall airmanship, but the weak correlation (0.08) between sex and performance was not statistically significant (Kantor:9-10). The U.S. Navy study cited above, while showing higher composite scores among male pilot candidates on selection tests, also showed identical grades for males and females in actual flight training (Blower:6).

Current tests are not good predictors of either success in completing pilot training or of later success as an aviator. The development of valid tests of mental, psychomotor, and psychological fitness for aviation is an area of current research interest (personal communication, Human Resources Laboratory, Brooks AFB, TX).

FEMALE ANATOMY AND PHYSIOLOGY

There are many obvious anatomic and physiologic differences between males and females. For example, females have a different average body composition. The mean percentage body fat of a 1985 sample of male and female recruits was 14.0% and 24.3%, respectively (Teves/see Strength references). The mean percentage body fat of samples of U.S. women in their early 20's have ranged from 21.5% to 31.0% (Clauser:1079/see Anthropometry references:154). Pilot candidates probably also fall within this range; one study of female Air Force Academy cadets found an average body fat of 24.8% (Cote/see Aerobic Fitness references). The impact of body composition on specific areas of performance is discussed in later sections. This section will discuss differences in male/female urinary /reproductive tract anatomy and the impact of cyclic hormonal fluctuations on performance.

Urine collection systems for certain ejection seat equipped aircraft with prolonged missions must be differently designed to accommodate females. This was recognized as a problem by Jaqueline Cochran in 1943 (Rock:151). A urine collection device -- Disposable Absorption Containment Trunk (DACT) -- has been adopted by both the USAF and National Aeronautics and Space Administration (NASA). Wearing this diaper-like device, females dressed in a full pressure suit tolerated 10 hour exposures without sequelae such as skin problems (personal communication, Dr Jane Otto, Beale AFB). The Strategic Air Command Scientific Advisory Board in evaluating potential problems in integrating females into U-2 (high altitude, long duration flying) determined that the use of the DACT combined with the use of a tampon for menstrual flow should prove satisfactory (Strategic Air Command Scientific Advisory Board/see Pregnancy references).

Another obvious physiologic difference between males and females is that females are subject to cyclic fluctuation in hormone levels. Two concerns

have been raised: the major concern is that the menstrual cycle may have an impact on female performance; a secondary concern is that the stresses of flight might affect the menstrual cycle.

There is disagreement about whether the phase of the menstrual cycle can affect performance. Specific physiologic parameters are definitely influenced by hormonal levels. For example, progesterone is a respiratory stimulant that increases the respiratory response to CO2 (Montes) (Kimura). Elevated progesterone and estrogen levels in the luteal phase (between ovulation and the menses) significantly increase the sweating threshold and body temperature when compared to the follicular phase (Kolka). However, studies of the relationship between phase of the menstrual cycle and physical performance have yielded varying results. Most studies have not demonstrated an effect of the menstrual cycle on physical performance (Hunt:47). In one study overall exercise performance was not affected by phase of the menstrual cycle (Dombovy). In other studies exogenous progesterone administered to male subjects was also a respiratory stimulant but did not change overall exercise performance (Kimura) (Bonekat). In another study the effects of hormones on body temperature regulation were evident at rest, but did not substantially affect heat tolerance during exercise (Horvath). Experience has not shown menstruation to be an impediment to operational military flying (Rock/see Anthropometry references:65,147).

There are many pitfalls in trying to study this area. First, hormonal status can affect performance of those with different levels of training differently (Hunt:49). Second, the effects of hormone can vary for different types of performance. One study showed an increase in ability to lift weights or row during and following the menses. Running performance, on the other hand, was poorer during and after the menses (Hunt:48). Third, studies of performance have to take into account the use of exogenous hormones. One study demonstrated cyclic variation in performance among normally cycling females that was not present among those on oral contraceptives (Hunt:48). Another study demonstrated that women with normal menstrual cycles and not

taking oral contraceptives demonstrated significantly greater hand steadiness than men, while women on oral contraceptives demonstrated significantly poorer hand steadiness (Hudgens). A third study demonstrated that normally cycling women had significantly lower hearing thresholds and less threshold shift following noise exposure (but only during certain phases of their menstrual cycle and at certain frequencies) than either women on oral contraceptives or men (Swanson).

Furthermore, the stress associated with occupational or avocational activities can effect the menstrual cycle. Female athletes, for example, often experience menstrual irregularities, but not pelvic discomfort, as a result of training (Hunt:49). In one study 39% of stewardesses experienced menstrual irregularities (Iglesias). Also 38% experienced pelvic discomfort after long flights (Iglesias). Another study confirmed these results showing that 28% of female stewardesses had menstrual irregularities with a common tendency for the time between menses to be prolonged in those on transmeridian routes *(crossing time zones)* (Preston).

AEROBIC FITNESS

The best measure of overall aerobic capacity is maximal oxygen utilization (VO_2 max). Men have higher aerobic capacities than women. The average VO_2 max for average young adults in the U.S. is 1.7 L min-1 for females and 2.7 L min-1 for males. Adjusted for body weight the difference is somewhat less: the average being 30 ml per kg for females and 40 ml per kg for males (Nunneley:37). Vigorous training further reduces these differences between men and women. In one series for example, male distance runners had an average VO_2 max of 61.7 ml min-1 kg-1 while female distance runners had 55.7 ml min-1 kg-1 (Nunneley:38) The female runners maintained a higher percentage of body fat--18.9% compared to 11.4% for males. Some of the observed differences between men and women may be due to differences

in muscle bulk rather than aerobic capacity (Washburn:954). If this increased fat is adjusted for by calculating VO_2 max in ml/min per kg lean body weight, then the values for female athletes are almost identical to male values: 68.9 ml/min per kg lean body weight versus 69.8 ml min-1 kg-1 lean body weight. One investigator remarked that "body fat is a burden only during locomotion" (Nunneley).

Women undergoing basic training experienced a greater increase in VO_2 max than did men undergoing the same training. Females, like males, demonstrated a loss of body fat. Females, however, actually gained muscle mass as a result of training (Patton:492). Pilot candidates might be expected to be more fit than the general population. For example, one study of female Air Force Academy cadets found an average VO_2 max of 46.1 ml kg-1 min-1 (Cote). Evidently the aging process in women causes a lesser loss of maximum oxygen consumption than in men (Hossack:799). Bedrest, simulating exposure to the zero-gravity conditions of space flight, appears to induce a similar loss of aerobic capacity in both men and women (Convertino:17) (Convertino:895).

Both males and females performed self-paced hard work proportional to their VO_2 max-- for load-bearing marches energy expenditure was approximately 45% of VO_2 max for both genders (Evans:613-621). The study comparing men and women carrying loads over a variety of terrains demonstrated male performance to be faster overall, although the range of performance for each sex was extremely wide with considerable overlap between the male and female group. When performance was adjusted for VO_2 max, all sex differences disappeared. Thus VO_2 max is the best predictor of ability to do hard work irrespective of sex (Evans).

III. ERGONOMIC ISSUES

ANTHROPOMETRY

There are obvious size and shape differences between the average male and the average female. Limited anthropometric data exists on female aviation populations. Available USAF data is from a 1968 study of 1,905 women (Clauser). Most of the subjects were obtained from two air bases in San Antonio and over half of this study's sample had medical or dental specialty codes; thus it may not be representative of the current Air Force population. A major study of USAF personnel using a laser scanner is planned; it would include a sample of approximately 2,000 females, including a sample of female pilots (personal communication, Kathy Robinette, Armstrong Aeromedical Laboratory). The mean stature of the average USAF female, as determined by the 1968 survey, was 64 inches (Clauser:73). Female aviation candidates are clearly not representative of the general population, as 64 inches is currently the minimum stature required to enter flight training (Air Force Regulation 160-43, 7-32-a(1)). Anthropometric data has also been determined for stewardesses by the FAA in a 1971 study of 423 trainees. The average height of 65 inches is explained by the fact that most airlines had a minimum stature requirement of 62 inches (range of 60 to 64 inches) (Snow). Anthropometric data for female military pilots is not available.

Aircraft cockpits are generally designed to accommodate men rather than women (deSteiguer). The range of body sizes that can be accommodated by modern aircraft cockpits is limited by many factors. Ejection-seat equipped aircraft, for example, are generally designed with adjustment of the ejection seat being possible only in the up-and-down direction with no forward and aft adjustment possible. Rudder pedals are designed to be adjusted, but control stick, throttle and other controls are not. Current standards, which exclude the smallest 5% of the male population, would exclude approximately 50% of the

female population. Accommodating a greater percentage of women would involve extending the design range. For example, a design range of 8 inches would accommodate 90% of the male population (all but the shortest 5% of males and all but the tallest 5% of males). A range of 13.9 inches would be required to accommodate all but the shortest 5% of females and all but the tallest 5% of males (McDaniel). Extending the design range would increase costs. The cost of aircraft or equipment modification would depend on the system being modified.

The issue is more complex than just size differences. Females are not simply proportionally smaller than men. Although the 50th percentile female may correspond roughly to the 5th percentile male, she will probably have larger hips and chest depth and smaller hands (Robinette). Female hip circumference is often proportionally larger than torso length or chest girth (Reeps). Females also generally have a shorter arm length than males of the same height (McDaniel, personal communication). A concern that has been raised is that the lower weight and lower average center of gravity among females might not be compatible with ejection seats as currently designed. The T-38 seat, for example, will tend to rotate backwards when ejecting a crewmember weighing less than 140 pounds (Rock:43).

Females are generally proportionally lighter in weight for a given height. The possibility that females might more easily sustain spinal injuries when using standard ejection seats has been addressed (Gragg). The Royal Air Force has reported a neck injury during ejection training of a 105 pound female (Turner). Dynamic Response Index Calculations estimate that the 5th percentile female weighing 99 pounds would be at a very slightly increased risk of injury (4% chance of injury) (Rock:49). No injuries, however, have been reported in the USAF among females on the ejection seat trainer (Rock:29).

Personal and protective equipment fitting presented a problem in integrating females into the pilot force. Increasing the number of sizes at the smaller end of the scale only partially solved the problem. Custom fitting can be expensive and time-consuming. Concern has been expressed that using

the medium size helmet mold (the smallest currently now available), female pilots' helmets may "sit somewhat higher on the head" with resulting instability while under $+G_Z$ acceleration and during ejection (Reep). Studies have also demonstrated that differing female facial dimensions can also cause difficulty with mask or goggle seals (deSteiguer). Care needs to be taken when fitting the parachute harness. The harness can rise from 4 to 8 inches as a result of compressing the buttocks during opening shock; this can cause breast injury if the chest strap is adjusted below the breasts (Reep). G-suits are manufactured only to fit those with a stature greater than 64 inches (50th percentile female and minimum height for acceptance into pilot training).

Current standards address only a very limited number of anthropometric variables such as height, weight, and sitting height. Good anthropometric measurements may be difficult to obtain outside the research laboratory, as evidenced by U.S. Air Force difficulty obtaining reproducible sitting height measurements on pilot candidates (HQ USAF/SGP letter, 27 April 90). Arm reach and leg clearance are not routinely measured on pilot candidates. Furthermore, current standards do not always represent what is actually required to meet the specifications of operational aircraft. Aircraft vary widely with respect to what sizes are accommodated. For example, a recent Canadian study demonstrated that 94% of females but only 61% of males fit adequately in the CT-133 Silver Star; this was because many males had inadequate head clearance (Rothwell). By comparison, only 19% of males and 10% of females fit in the CH-136 Kiowa; this was usually due to a combination of leg length deficiency and/or lack of head clearance. Thus the question of female adaptability to various cockpits cannot be entirely answered. Our knowledge both of pilot anthropometry and of cockpit requirements is incomplete for both males and females. More research is needed in this area.

STRENGTH

There are obvious fitness and strength differences between the average male and the average female. One of General Hap Arncld's original concerns was that females may not be capable of the strength required to manipulate flight-controls in aircraft such as the B-17 (Holm:314/see Introduction references). This concern has been echoed even about more modern aircraft such as the C-130 Hercules (Turner/see Anthropometry references). Jaqueline Cochran argued as early as 1943 that "not only is muscular strength beccming less and less of a factor in the piloting of our planes, but also selected women in large numbers are available who have sufficient size and strength for these tasks" (Rock:see Anthropometry references:149). Unlike aerobic capacity, there are many relevant measures of strength that are not necessarily well correlated with each other. The overall strength of an adult female is about two-thirds that of an adult male. Leg strength in women is closer to that of men (71.9% that of males) than arm strength (55.8% that of males) (Laubach:535). These overall statements, however, hide even more variation in specific strength measurements. For example, ankle plantar flexion (pushing off with the toes) in women is on the average 86% (Laubach:540) that of men whereas women performing a backward push are only 35% as strong as males (Laubach:536). In the cockpit environment this decreased strength is compounded in a cockpit that does not adequately accommodate female size differences (Karim:9).

As with aerobic work, however, most of the sex differences in lifting and carrying capacity disappear when lean body mass is controlled for. Female isometric strength (63% that of males) and lifting strength (55-59% that of males), was 86% and 75-82% that of males when normalized for lean body mass (Teves). Likewise, female mean power (48% that of males) and peak power (53% that of males) on the Wingate test, was 79% and 76% that of males respectively when normalized for lean body mass (Murphy).

Few studies have been performed simulating an actual aviation environment. The FAA studied the ability of women to meet current strength limits of aircraft controls in a realistic flight simulator. Nineteen out of 24 women (79%) were able to maintain the required 150 pounds of rudder pressure for 30 seconds required for control of a civil aviation aircraft (Leeper). The maximum elevator pressure that could be exerted by any of the 24 women in the study was 55 pounds, while regulations specified 75 pounds for 20 seconds. The maximum aileron deflection that any women could exert was 22 pounds while 60 pounds for 20 seconds was required (Leeper). Thus female upper extremity strength may be insufficient to exert required control forces during emergencies. One study showed a positive correlation between both height and weight versus strength. As the average height of his 24 civilian pilot subjects was only 64 inches, his results have only limited applicability to the taller military pilot population with a minimum height requirement of 64 inches. However, an Air Force study yielded similar results; a 1981 study of the strength of 61 male and 61 female physically fit volunteers meeting USAF height and weight criteria for pilots demonstrated that female arm strength was much less than that of males and often below military design criteria. Leg strength among females was less than that of males, but was usually sufficient to meet military design criteria (McDaniel). Males and females obtained similar benefits from strength training programs (McDaniel). Weight training resulted in a proportional degree of improvement in men and women (Marcinik).

In spite of these considerations, females capable of meeting current standards do not routinely have difficulty with reach or strength. However, there have been some instances of difficulty; for example, some females have had difficulty pulling the ACES II handle designed for center pull with one hand (McDaniel, personal communication). A civilian study from Australia demonstrated that many females cannot exert the 10 kg force for 0.25 sec on the ripcord that is the FAA standard (Bullock:1177-1183). Whereas only 10% of Australian parachutists are female, females constitute one-third of the fatalities in parachuting accidents, and half of all parachuting fatalities are due

to failure to deploy the main or reserve chute (Bullock:1177-1183). An Air Force study gave similar results; the average male could exert 1.8 times the strength of females in ripcord pulls. For each of the three two-handed pulls tested, almost all the men (104/104, 104/104, and 102/104) but only about 90% of the women (97/107, 96/107, and 97/107) could make the required 27 pound pull (Aume:51).

While there are apparent, large differences in strength between males and females, most of the difference is accounted for by males' greater lean body mass. Male-female strength differences may become of less operational significance in the cockpits of modern fly-by-wire aircraft. Studies have demonstrated that "gender-free" standards can be developed (Beckett).

IV. RESPONSE TO AEROMEDICAL STRESSORS

ACCELERATION FORCES

G stress is a serious problem in certain types of military aviation and acrobatic flight. A study comparing the +Gz (headward acceleration or eyeballs down) tolerance of 102 women and 139 men found no significant differences in tolerance of exposures up to +7 Gz (Gillingham). There was a strong negative correlation between height and G tolerance, and a weaker positive correlation between weight and G tolerance. Thus the females' G tolerance benefited by their being on the average shorter than males, but their tolerance was adversely affected by their being on the average lighter than males. When height and weight were controlled for, females had a slightly lower (but not significantly so) +Gz tolerance. Menstruation had no effect on G tolerance. No breast discomfort was reported. The only unique problem encountered by the females was urinary stress incontinence in 2 subjects.

The effect of prolonged weightlessness on G tolerance has also been studied. One study demonstrated a greater loss in tolerance to +3 Gz following 14 day bedrest in males (12% of baseline) than in females (33% of baseline) although these differences did not achieve levels of statistical significance. Also in this study, females appeared to recover their +Gz tolerance more quickly (recovered to 79% of baseline in 3 days) than males (recovered to 26% in 3 days) (Newsom). In another study, however, women appeared to lose about 50% more G tolerance than males following 14 days of bed rest (Greenleaf:71). The males and females in this study, however, were not treated in an identical manner in that the males were given prescribed exercise on a bicycle ergometer at 50% of VO_2 MAX for 30 minutes daily during the two weeks ambulatory control period preceding the two weeks bedrest period and the females were not. A third study by Hordinsky found greater loss of orthostatic tolerance in females; short duration (6 hours) bed rest caused a 6% decrease in orthostatic tolerance among males compared to a 21% decrease among females (Hordinsky). All of these studies were limited by small sample sizes; 12 in the Greenleaf study, 7 in the Newson study, and 11 in the Hordinsky study.

Motion sickness is a relatively common problem in training, but a much less common problem operationally. Several authors have alleged an increased susceptibility of females to motion sickness. An FAA study found that among an undergraduate student population more women than men report susceptibility to motion sickness ($p<.001$) on a 20-item questionnaire (Lentz). Another study, however, found no differences between men and women for duration and number of beats of nystagmus, sensations of turning, or after effect durations. Women did, however, have more slow phase nystagmus (Lentz). The relationship of nystagmus to motion sickness, however, is controversial. The alleged increased susceptibility of women to airsickness is not explained by current theories of motion sickness (Reason:268). Increased reporting rather than an actual increased incidence is a possibility.

HYPOXIA

Hypoxia would be a .isk only in the event of simultaneous loss of cabin pressure and failure of personal oxygen equipment at altitudes above approximately 10, 000 feet. Several studies have demonstrated comparable tolerance to acute hypoxia in men and women (Wagner:1223) (Drinkwater:657). Some minor physiologic differences, however, have been noted (Wagner:367). Most studies of breath holding have shown a bradycardia response to apnea in both men and women. One study, however, has shown a tachycardia response in women to successive apnea episodes (Sebert:486). Female work capacity under acute hypoxic conditions is less than ıor males due to a limited ability to increase ventilation. Females, however, tolerate sub-acute hypoxia better than males (Elliott).

Females are perhaps more resistant than males to chronic hypoxia or altitude sickness. Women have been reported to be less susceptible to the gastrointestinal and cardiovascular symptoms associated with acute mountain sickness (Harris:1166). More recent studies have confirmed this lessened susceptibility to acute mountain sickness (Kramar:119). Prolonged altitude exposure results in comparable acclimatization in men and women although some differences of unknown significance have been noted. For example, women respond to altitude exposure with a lesser increase in hematocrit than men (Drinkwater:475).

DECREASED BAROMETRIC PRESSURE

Decompression sickness would be a risk in the case of unpressurized aircraft or loss of cabin pressure above approximately 18,000 feet. Epidemiologic studies of the rates of decompression sickness in males and

females have been apparently contradictory. A study performed at the USAF School of Aerospace Medicine in 1973 showed ten times as much decompression sickness (DCS) in women as men (Bassett:241). The female and the male group were not, however, comparable in other respects: most of the males were trained aircrewmembers undergoing refresher training, whereas the females were flight nurses undergoing initial training. A newsletter survey of Southern California diving instructors found a 3.3 time increase in decompression sickness in the female divers (Bangasser). The self-selection by responders to this survey, however, introduces a huge potential for bias. Neither of these studies were published in peer-reviewed scientific journals. In contrast, an increased incidence of DCS was not found in a U.S. Navy study of 28 female and 488 male professional divers (Zwingelberg).

Laboratory studies of altitude DCS included a USAF School of Aerospace Medicine (USAFSAM) study comparing 30 males and 30 females exposed to 7.8 psia for 6 hours. Five (17%) of the females but only 1 (3%) of the males developed DCS. Interestingly, all of these 5 females were menstruating or in the early phase of their menstrual cycle. More males (73%) than females (43%), however, had bubbles detectable by precordial ultrasonic Doppler monitoring (Dixon:1146-9). In 1990 Rudge reported a retrospective review of decompression sickness cases at USAFSAM that showed an increased rate of decompression sickness in females during or just after menstruation (Rudge). This study was limited by lack of information on the use of exogenous hormones such as birth control pills in the population being studied.

TEMPERATURE EXTREMES

Exposure to environmental temperature extremes is of importance in a survival situation and in certain operational settings. Women have been said

to have an advantage in tolerating cold exposure; this has been attributed to increased body fat. Aquatic life is harvested by Korean divers who traditionally have used no wet-suits in water as cold as 10 degrees C. In Korea this profession is exclusively female -- a fact attributed to their greater resistance to cold immersion. Studies comparing Korean males (mean body fat of 15.1%) and females (mean body fat of 21.0%) found lower critical water temperatures and higher insulation values for the female subjects (Kim). Both increased subcutaneous fat and "an elevated shivering threshold" have been suggested as possible reasons for the increased cold tolerance of the female divers (Rennie). Women maintain a higher core temperature (esophageal temperature) for a given skin temperature than men. The percentage of body fat is better correlated with core temperature response in women than in men, probably because of a different and more protective distribution of this body fat.

Not all studies, however, demonstrated this female advantage. When percent body fat is controlled for, men at rest in cold water demonstrated less heat loss than women of similar percent body fat (McArdle:1568). This may be because thin women have a higher surface-to-mass ratio than thin men (McArdle:1570). An additional observation was that thin men demonstrated a greater increase in oxygen consumption (spontaneous thermogenesis) than thin women at comparable water temperatures. Men tended to shiver earlier and to maintain higher skin temperatures than women (Walsh). During exercise, however, the same females appeared to do somewhat better than their male counterparts, although these results did not achieve statistical significance (McArdle:1576). The authors speculated that increased fat insulation in the extremities of the exercising females may explain this. Cardiovascular responses to facial cooling were similar in males and females (Mannino:29-30).

Men may have some advantage on heat exposure. Eighteen men and 17 women were compared on their ability to perform mental tasks while wearing chemical protective gear (MOPP IV) in a hot environment (91 degrees F, 61% relative humidity) for seven hours. Only 7 out of 17 females were able

to complete the task, whereas 16 out of 18 males did so (Fine). Female and male subjects in this study were equally well trained in performing the simulated fire direction task in MOPP IV dress, but personal characteristics such as fitness were not controlled for. One male advantage was their increased ability to sweat. This may be a potential disadvantage, however, in a chemical environment; many of the males in the above 7-hour study sweated through their protective clothing. Some studies attempted to distinguish gender-related thermoregulatory differences between hot-dry and hot-wet climates; females had lower heart rates and rectal temperatures in hot-wet whereas males were lower in hot-dry climates (Shapiro:7).

Many of these studies addressing heat tolerance, however, did not control for the physical fitness of the participants. Several studies did not find differences between men and women when fitness and heat acclimatization were controlled for (Avellini) (Frye) (Horstman).

RADIATION

Radiation is a potential hazard of high-altitude flight (above approximately 50,000 feet). Exposure to ionizing radiation causes an increased risk of cancer of all types roughly proportional to the magnitude of exposure, although the exact shape of the dose response curve is unknown. Differences in male and female anatomy and physiology may affect the epidemiology of radiation-induced disease. The risk to females appears to be perhaps 50% higher due mainly to the additional risk of breast cancer (McCormack:343). Although the magnitude of this risk is still negligible during atmospheric flight, space flight may necessitate lower career radiation limits for female astronauts (McCormack:344).

Particle radiation is a danger unique to flight outside the earth's atmosphere. In recent studies proton irradiation of female rhesus monkeys has

been shown to triple the incidence of endometriosis. Incident energy and dosage ranges were variable but an increased incidence of endometriosis was noted even in monkeys exposed to less than 113 cGy (Wood:719). Because of these concerns, it has been recommended that prospective female astronauts limit their career exposure to 25 rem to the uterus (Wood:301).

Another danger of radiation exposure is sterility. Temporary infertility, at least, is more readily induced by acute exposures to radiation in men than in women. Doses required to produce sterility, however, are generally above recommended limits based on risk of cancer.

V. MEDICAL EFFECTS

ILLNESS AND INJURY

Males and females have a different incidence and prevalence of many diseases of aeromedical importance. Males are at apparently a greater risk for medical incapacitation than females. Overall males have an 80% higher mortality than females in all age groups (Syme:958) (Rice:7/see Pregnancy references). Of the 15 leading causes of death, males have a higher rate for all causes except one -- diabetes (Hunt:11/see Anatomy and Physiology references). Cardiovascular disease is the biggest cause of disqualification for flying duties, and males have double the disease incidence of females for cardiovascular disease (Kilbourne:707) (Hunt:11) (Rice:9). In the civilian pilot population heart disease is also the leading cause of inflight incapacitation (in the USAF it is the second most frequent cause, following seizures). The decreased frequency of coronary heart disease in females could make them a better risk than males from the point of view of incapacitation from medical causes. Females, however, have a higher incidence of the congenital cardiac

defect, mitral valve prolapse, which is not infrequently diagnosed in apparently healthy aviators.

While females are probably a better risk than males from the point of view of permanent medical disqualification or incapacitation, they may be subject to higher rates of morbidity than males (Rice:1). Females are less likely to report their health as "excellent" (Rice:15). Females generally report more symptoms than males and visit physicians more frequently than males (Mechanic:972). They have higher rates of physician visits, dental visits, and hospitalization (Rice:18). Female trainees in one Army study had 40% more clinic visits for illnesses than men. Most of this difference was accounted for by gynecological complaints in women (Jones BH). In the U.S. Army, females accounted for 6.7% of aviation medical losses while accounting for only 1.2% of the aviator population; one-third of female losses were due to pregnancy (Edwards:3,5).

There are also more injuries among women than among men when exposed to the stresses of basic combat training. A review of the incidence of stress fractures in military trainees found that the relative risk for females was increased in the four studies addressing male/female differences-- relative risks ranged from 3.8 to 10.0 (Jones BH:385). Another study of 124 men and 186 women basic trainees found an injury rate of 51% among the females compared to 27% among the males (Jones BH:18). When these percentages were adjusted for fitness level as measured by mile run time and number of pushups performed, however, the male/female differences disappeared (Jones BH:32).

Psychiatric illness has a higher incidence among stewardesses (20%) than among stewards (10%) or flight deck personnel (1-2%) (Blanc). The incidence of psychiatric illness in USAF aviators is unknown. However, during the 6 years following the initiation of female pilot training (October 1976 - September 1982), 17 females were referred for psychiatric evaluation at the USAF School of Aerospace Medicine out of a total of 2,701 such evaluations among all USAF aviators (Jones DR). Fifty-three percent of the females

evaluated were returned to flying duties compared to 64% of the males evaluated.

PREGNANCY

Females of an age to be active military pilots would also be susceptible to becoming pregnant. The ability of females to continue flying duties while pregnant is an area of controversy. The two major concerns would be the effects of pregnancy on ability to perform and the effects of the aviation environment on the fetus.

Basic anatomy and physiology are significantly altered during pregnancy. For example, the respiratory response to hypoxia is increased perhaps contributing to dyspnea (shortness of breath) during pregnancy (Grindlay). Orthostatic intolerance was twice as frequent among those 11 weeks pregnant than among non-pregnant controls (Hunt:51/see Anatomy and Physiology references). Although no centrifuge studies have been done on pregnant subjects, this orthostatic intolerance would perhaps be expected to contribute to lower G tolerance during pregnancy. Authorities have cited danger of incapacitation due to spontaneous abortion, nausea and vomiting, and other complications as a reason for restricting flying as early as the first trimester. Weight gains during pregnancy are additional rationale for restricting flying duties during the third trimester (Anderson). Weight gain and unsteadiness were cited by one investigator as reasons for stewardesses to stop flying as early as 13 weeks of gestation (Scholten).

The effect of working on pregnancy outcome has also been an area of controversy. One study found associations between several occupational groups and adverse outcomes of pregnancy; factors suggested as significant included long work hours, heavy lifting, some chemical exposures, and exposure to infectious diseases (McDonald). In another study premature birth

has been associated with occupational fatigue factors such as prolonged standing and physical effort (Mamelle). These associations between work and adverse pregnancy outcome were not confirmed by other studies (Marbury). Specific aviation-related concerns have been expressed about potential effects of hypoxia, decompression sickness (Rayman:165), and radiation.

Although extreme hypoxia has been associated with fetal loss, there is no evidence that cabin altitudes maintained by commercial aircraft (5,000-7,000 feet) pose any hazard to the fetus (Cameron). Oxygen saturation of fetal hemoglobin drops less precipitously than maternal hemoglobin on exposure to decreased partial pressures of oxygen (Moser:579). The effects of chronic hypoxia have also been addressed. Several studies have demonstrated an apparent tendency for infants born to mothers living at high altitudes to be of lower birth weight. These studies, however, may have been flawed by such factors as preexisting malnutrition in the mothers residing at altitude. A recent study in Leadville, Colorado, demonstrated that birth weights of infants born at high terrestrial altitudes were not decreased by exposure to these altitudes (Cotton).

Animal studies have suggested that decompression sickness may be a risk to the fetus in both the early months of pregnancy (Gilman:31) (Jennings:370) and the third trimester (Stock:776) (Fife:287). There is an increased rate of low birth weight infants (44.6%) reported among Ama divers from Japan and Korea. These divers who continue to work during pregnancy, however, are exposed to many potential stressors, including changes in barometric pressure, cold, and hard work (Magaletta:88). A U.S. study compared 109 female divers who continued to dive during pregnancy with 69 who discontinued diving and found a 5.5% incidence of birth defects in the former group compared to 0% in the latter ($p<0.05$) (Bolton). This study, however, solicited questionnaires by advertising in diving journals and thus biased self-selection of the study participants was certainly possible. Also the possible confounders, such as physical work, were not controlled for in these studies.

Among the stressors in the aviation environment, the risks of radiation exposure during very high altitude or space flight is perhaps the best documented risk to the fetus. Radiation poses additional risks of congenital malformation and mental retardation that preclude participation of pregnant females in space flight (McCormack/see Radiation references:344). There is another risk to the offspring of exposed females in that radiation (intrauterine X-rays) has been possibly linked to a higher incidence of leukemia and a higher death rate from other causes during the first ten years of life (Diamond:283-313). The National Council on Radiation Protection and Measurement recommends that exposures during pregnancy not exceed 0.5 rad (Council on Scientific Affairs) (Hunt:63).

Heat is another known teratogen, but only core temperatures above 38.9 ° C (102° F) to 40° degrees C (104 °F) are likely to be harmful (Council on Scientific Affairs). Temperatures of this magnitude due to heat stress in an aviation environment are unlikely except in the most extreme aircraft malfunction or survival situation. Environmental temperatures sufficient to cause this level of hyperthermia are not readily tolerable on a voluntary basis (Council on Scientific Affairs). Although some controversy does exist about the effects of acceleration, radio-frequency radiation, noise, or vibration (Bantle), there are no <u>known</u> adverse effects of these on the fetus (Council on Scientific Affairs) (Hunt: 75,82).

Strategic Air Command Scientific Advisory Board recently studied the risks of integrating female pilots into high altitude U-2/TR-1 flying. Risks to the fetus were felt to be the major significant risk. The Board was specifically concerned about radiation exposure; the monthly exposure of a U-2 pilot of 300 mrem is 60% of the 500 mrem felt to be the safe limit for fetal exposure during the first trimester. Decompression was a concern, but the risks were felt to be minimal during the initial stages of pregnancy -- before placental development exposes the fetus to maternal blood. Hyperthermia, occasionally a problem in the U-2, was an additional concern. The Board recommended contraception, with pregnancy testing every 14 days.

Current recommendations regarding pregnant females flying as crewmembers or as passengers differ among the various authorities. Currently the USAF allows for waiver of female pilots to continue flying non-ejection seat aircraft within the United States until the 24th week of gestation. An additional restriction prompted by concerns about the effects of decompression on the fetus is the prohibition against Physiologic Training (altitude chamber training). U.S. Army policy allows air traffic controllers to perform duty throughout pregnancy, but restricts rated aviators from flying duties. As noted above, pregnancy among female aviators in the U.S. Army, accounted for one-third of female medical losses (Edwards:5). The FAA Regulations leave the decision up to the female pilot's physician; in the usual case, however, flying is continued through the first two trimesters (personal communication FAA). American Airlines allows females to travel as passengers up to one week before and starting one week after delivery with no specific precautions other than arrangements for an extended seatbelt (personal communication).

VI. CONCLUSIONS

There is historical evidence that women are capable of being excellent aviators. Although women have been integrated into many aspects of military flying, they remain restricted from certain combat aircraft and missions. There are some differences between males and females in the general population in cognitive performance testing, but the magnitude of male/female differences is not great. The sex-related differences although statistically significant, account for only a very small part of the population variance- - Hyde estimates that these differences account for no more than 1% to 5% of the variance within the population. Moreover, the validity of using these differences to predict aviation performance is unknown. Pilot training attrition may be too variable and insensitive a criterion on which to base generalizations about female aptitude. Although cognitive performance and good judgment are perhaps the most

important attributes of a military pilot, the ability of current selection tests to predict these attributes in either men or women has not been demonstrated.

Anatomy and physiology present no insurmountable problems to females participating in military aviation. Practical considerations such as urine collection are being addressed and do not appear to be an insurmountable obstacle. The Strategic Air Command Scientific Advisory Board in studying the integration of female pilots into U-2/TR-1 flying determined that urination and menstruation would be satisfactorily handled by the DACT and tampons. The effect of hormonal fluctuation on performance is complex and poorly understood; studies need to take into account the type of performance being studied, the level of training of the subjects, the use of exogenous hormones, as well as the phase of the menstrual cycle. Because female performance might vary at various parts of the menstrual cycle or on oral contraceptives, this might result in a wider range of performance among female subjects. Most studies of performance reviewed did not accurately define the hormonal status (time of the menstrual cycle, use of oral contraceptives, etc.) of the subjects. While the average female is less aerobically fit than the average male, selected females are capable of degrees of aerobic fitness equal to males. For overall fitness, VO_2 max is predictive of ability to do prolonged work irrespective of sex.

Most anthropometric and strength problems faced by females are a result of aircraft being designed for men rather than for women. The issues are political, economic, and engineering rather than medical. It seems appropriate and feasible to devise size and strength standards, irrespective of sex, for aviation candidates. Men are, on the average, larger and stronger than women although there are large variations within each sex and a large overlap between the sexes. Most of the observed male/female differences in work performance, injury rate, etc., disappear when size, strength, and fitness are controlled for. Size criterion for flying duties is more a policy and economic decision than a medical one. Building cockpits to accommodate a wider size range will obviously entail engineering difficulties and costs.

In their respective responses to aeromedical stressors, several minor differences of questionable operational significance may exist between men and women. One aeromedical stressor currently causing significant operational losses is +Gz acceleration forces (G-induced loss of consciousness). There is no significant difference between males and females in tolerance to up to +7 Gz. As it is possible that the less muscular females would have difficulty with higher G levels, studies of tolerances above +7 Gz need to be accomplished. Studies on the effect of weightlessness on acceleration tolerance and of motion sickness have been inconclusive, possibly due to the small sample sizes of the studies. Women may be more susceptible than men to motion sickness.

Most of the studies discussed addressing decompression sickness are not published in the peer-reviewed scientific literature. Some of these studies have flawed methodology, such as relying on mail surveys with low or unknown response rates or comparing populations that are not really comparable in other respects (for example, comparing female flight nurses with male pilots). Rudge, however, convincingly demonstrated that females may have an increased susceptibility to decompression sickness during and just after the menses. This is unlikely to be operationally significant in aviation although it may be significant in certain selected exposures such as deep water diving or extra-vehicular activity during space flight. More research into this area is needed.

Females tolerate subacute and chronic hypoxia better than males. This is more likely to be of significance in travel to high terrestrial altitudes (mountains) than in aviation. The possible sex-related differences in heat and cold tolerance are unlikely to be of operational significance except during the unlikely event of a survival situation just at the limits of human tolerance. Even these small differences tend to disappear when fitness and body composition are controlled for.

There are important differences between men and women in their susceptibility to various diseases. Women are apparently more at risk of

radiation-induced cancer. Women may be less prone than men to sudden incapacitation. However, they may be subject to more temporary restrictions from flying duties. This would be especially true if down-time due to pregnancy is counted. The major concern with regard to the fetus is radiation exposure in high altitude/space flight. Other possible dangers include exposure to decompression sickness and extreme heat. Pregnancy also probably would increase female susceptibility to sudden incapacitation and perhaps lower +Gz tolerance.

It is recommended that research efforts to develop cognitive, psychomotor, and psychological tests to select aviators should continue. Valid tests could then be applied to both males and females to select the small sub-group suitable for military aviation. Selection criteria should address size, strength, and fitness requirements without reference to sex. Pregnancy and the possibility of fetal damage in the early stages of pregnancy (before diagnosis of pregnancy) appears to be perhaps the biggest single medical concern in allowing women unrestricted access to all aviation/space related careers.

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* U. S. GOVERNMENT PRINTING OFFICE: 1991--561-052/40061